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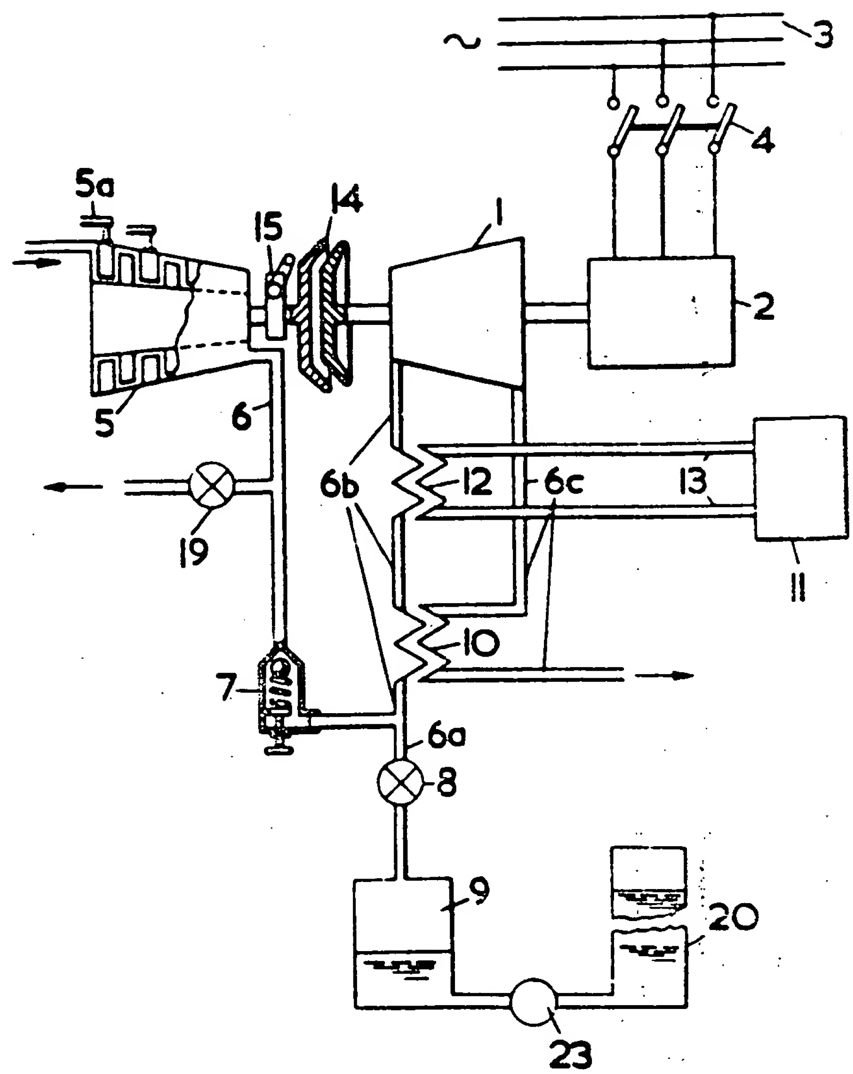

FIG. 1.

772,287 COMPLETE SPECIFICATION
2 SHEETS

This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2

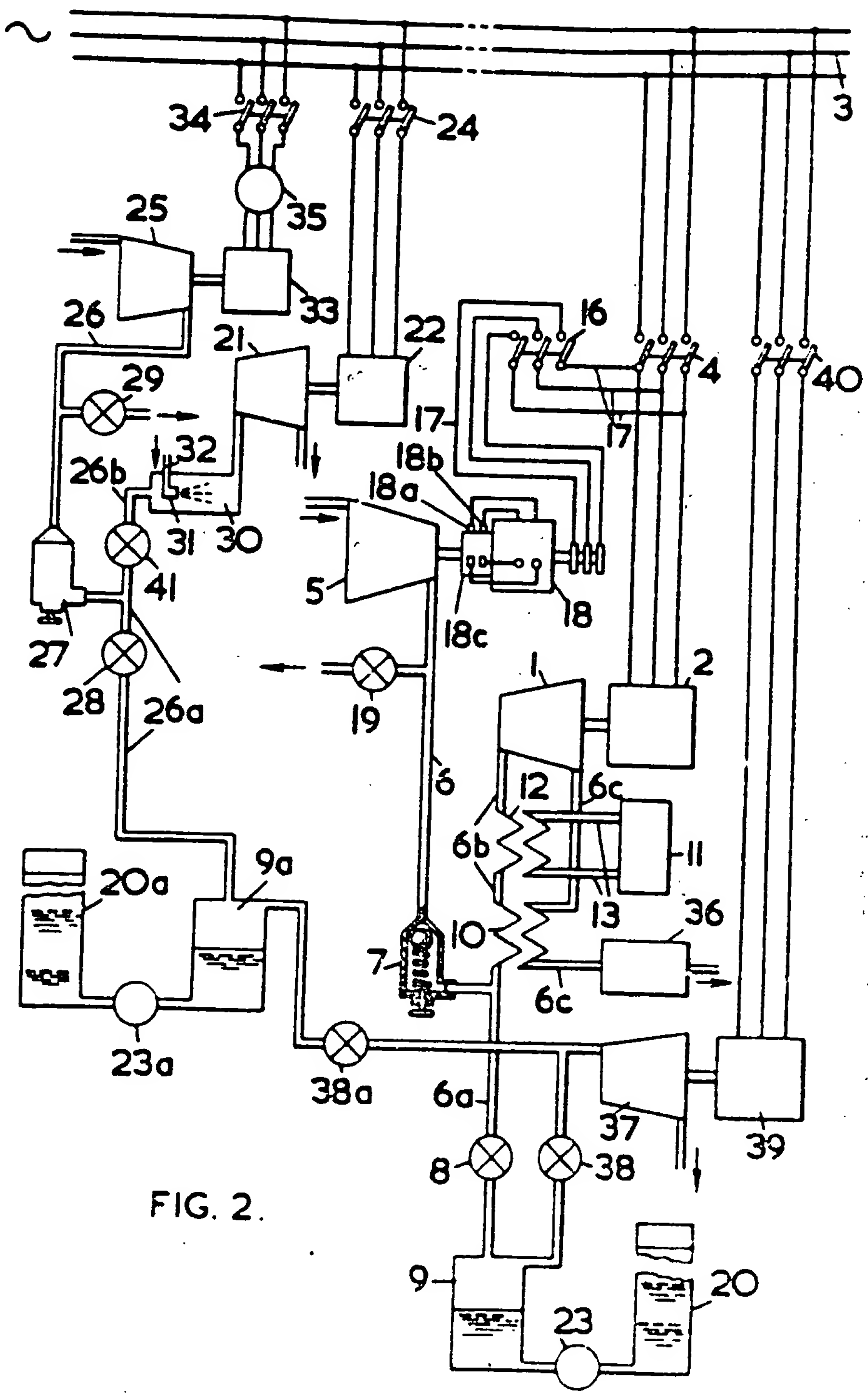

FIG. 2.

PATENT SPECIFICATION

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772,287

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International Classification:—F02c.

COMPLETE SPECIFICATION

Power System Incorporating a Gas Turbine

We, POWER JETS (RESEARCH AND DEVELOPMENT) LIMITED, a British Company, of 25, Green Street, London, W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

In the common form of continuous combustion type gas turbine plant an air compressor driven by the turbine itself supplies air which is heated by a heating arrangement—e.g. a combustion system burning fuel in the air—to provide motive fluid for the turbine. Usually, for each 1 h.p. of useful output the compressor requires about 2 h.p. to drive it and the turbine has to have a power capacity of about 3 h.p. This makes a total capacity of about 5 h.p. for the two machines. The heating arrangement must have a minimum capacity corresponding to the useful output—i.e. it has to be able to supply power equal to the useful output plus losses, whatever may be the actual capacity of the rotary plant.

In many types of power plant the prime mover is seldom loaded fully for more than a small part of the day and may be entirely unloaded for a part of the day; industrial loads, for example, usually continue for about only eight hours out of each twenty-four. Thus if the combustion system of the common form of plant outlined above be replaced by some form of heat exchanger for heating the air by transference of heat from an atomic pile or other heat source of high capital cost, this source is utilised uneconomically by being used for only eight hours a day, instead of being employed as a continuous and steady source of heat for twenty-four hours a day.

To reduce the bulk and cost of the rotary machines it has been proposed to supply a gas turbine with combustion products produced by burning fuel in air drawn from an air-storage reservoir, located underground, and supplied with air by any form of compressing means independent of the turbine, which accordingly does not drive a compressor.

The present invention is concerned with an arrangement for enabling a part-time load to be supplied, the bulk and cost of the rotary plant being reduced. One particular and important form of the invention is an arrangement wherein the bulk and cost not only of the rotary plant but also of the heater are reduced by keeping the turbine running for longer periods than the load lasts and preferably continuously. One aspect of the invention makes use of the fact as set forth above, that the power necessary to supply the air for the turbine is about twice the useful power output, to allow the turbine to be used to drive the load for one-third of the day and to pump air for storage for the remaining two-thirds of the day.

The invention consists in a power system including a compressed air storage reservoir for supplying air to a gas turbine, a source of heat for heating the air on its way from the reservoir to the turbine, a charging compressor for supplying air to the reservoir, energy supply connections from the turbine to means absorbing the useful power of the system and to the charging compressor for sharing the turbine energy between these two, and means for varying the turbine energy supplied by the energy supply connection to the charging compressor so that the latter can absorb turbine energy on occasion. The compressor energy thereby supplied may possibly be reduced to zero as the load increases, and means may be provided for establishing and interrupting the energy supply connection to the compressor. In particular there may be an engageable and disengageable driving connection between the turbine and the compressor unit.

Plant according to the invention furthermore may be made up of a turbine unit

h.p. capacity substantially equal to and at least as large as the full load h.p. of the external load, a compressor unit of about the same capacity in driving connection with the turbine, and adapted to supply air to the turbine, and air-storage reservoir adapted either to receive air from the compressor unit or to supply air to the turbine unit, means for controlling the supply of air from the compressor unit to the reservoir, and possibly interrupting the driving connection between the compressor and the turbine at will, and means including a heat source for heating the air on its way to the turbine. Where the gas turbine is driving an electric generator, the load then being removed from the turbine by switchgear disconnecting the output circuit of the generator from an electric network, the compressor may be driven by an electric motor supplied by the generator and switched on when the load is switched off. In a further modification, the generator in such a gas-turbine-driven electric generating plant may operate in parallel with other generators driven either by gas turbines or by other prime movers and possibly in several interconnected power stations, to supply current to an electric supply network.

One arrangement of power plant according to the invention is shown in Fig. 1 of the accompanying drawings and a second arrangement in Fig. 2 thereof.

In Fig. 1 a power system includes a gas turbine 1, and electric generator 2 driven thereby and an electric supply network 3 to which the generator supplies energy (derived from the turbine) through switchgear 4 which can be opened to interrupt the energy-supply connection. A compressor unit 5 can supply air through piping 6 and air-supply controlling valve 7 to where the piping divides into branches 6*a* and 6*b* and thence either by branch 6*a* and valve 8 to the air storage reservoir 9 or by branch 6*b* to the turbine 1. The valve 7 is a non-return valve having also operating means for closing it—e.g. by hand. Connected to pipe 6 is also the vent valve 19 for venting the compressor outlet to atmosphere. On its way to the turbine the air is heated by the usual waste-heat-recovery heat exchanger 10, and by the heating system 11—12—13 mentioned more fully hereinafter. Gases are discharged from the turbine through piping 6*c*, passing, on their way, through the said heat-exchanger 10. A driving connection between the compressor and the power system can be established and interrupted at will by the engageable and disengageable coupling 14 between the turbine 1 and the compressor 5. This coupling can be a positive or frictional clutch or an electric or hydraulic coupling, and actuated in conventional manner.

The turbine 1 has a h.p. capacity sufficient to drive only the generator 2 at full external load. In conventional gas-turbine plant the turbine 1 would require to be three times this capacity. The compressor 5 has about the same capacity. If the turbine 1, relieved of external load by opening of switch 4, and coupled to the compressor 5 by engagement of coupling 14, be run for example for 16 hours, about one-third of the output of the compressor 5 will be available to pump into the reservoir 9 a sufficient quantity of air for eight hours running of the turbine; thus for the next eight hours of the day the turbine 1, disconnected from the compressor 5, but driving generator 2 connected to net-work 3 by switches 4, can be used solely to drive the external load, the air for the turbine being supplied from the reservoir 9 at about twice the rate at which it was stored. The capacity of the heating system 11—12—13 will correspond to the power output for storing the air—i.e. to about one-third of full load; when load is being driven, the remaining two-thirds of the power is derived from the energy in the stored air. The air-heating system is made up of a source of heat 11 such as an atomic pile, from which heat is transferred to the air in piping 6*b*, by the heat exchanger 12 which may pass the air and a stream of fluid—in particular of molten metal—circulating through piping 13 and directly heated by the pile. Such a heating arrangement is inherently of expensive construction and the reduction in its capacity may be economically much more valuable even than the reduction in the bulk and cost of the rotary plant 1—5. The source 11 could be some industrial plant which operates all day and normally dissipates large quantities of heat.

The valve 7 can be operated to control the supply of air from the compressor unit to the reservoir 9. When clutch 14 is disengaged to bring the compressor 5 to rest, the vent valve 19 is opened to vent the compressor to atmosphere, whereupon the valve 7, being a non-return valve, will close automatically by the pressure in reservoir 9 and so interrupt the air connection between the shut-down compressor 5 and the reservoir 9 while leaving the latter connected through the heating means 10 and 12 to the turbine.

The machine 5 is a variable-output compresser, so that it can be brought into operation to supply air at a low rate to the reservoir 9 while the turbine 1 and generator 2 are supplying an external load reduced below full load. For this purpose the compressor is such that its output can be adjusted to various different values over a range, up to full output when there is no external load e.g. the compressor may be variable by swivelling the blades by conventional mechanism indicated at 5*a* or may be driven at variable speed through a variable torque converter such as the variable gearbox 5. In any case there may be one compressor for supply [illegible] the heater and turbine and another for [illegible]

the air to the reservoir. The latter may be disconnected from the rest of the plant by closing valve 8. The output of the turbine 1 may be varied,—e.g. by conventional variation of partial admission thereto.

In Fig. 2 the compressor 5 is put in driving connection with the turbine 1 by an electrical transmission. The clutch 14 is omitted; the electric motor 18 is coupled to and drives the compressor unit 5. The motor 18 can be connected to the generator 2, through the switch 16 and the connecting wires 17, and its speed can be varied as hereinafter set forth. Parts 3, 4 and 6 to 13 are as in Fig. 1. The switch 16 can be closed when switch 4 is opened so that the turbine 1 drives the compressor unit 5 when it is supplying no external load, or the motor 18 can be regulated to drive the compressor 5 at slow speed for low output when the external load on turbine and generator 2 is below full load so that the total output from turbine and generator is maintained at or raised to full-load value.

The generator 2 is coupled to a power network 3 as well as to the motor 18. Also coupled to the network 3 is the further compressor unit 25 shown as driven by the variable speed electric motor 33 supplied from the network 3 through switch 34. A gas turbine 21 may drive a generator 22 supplying network 3 through switch 24. Pipe 26 connects the compressor to valves 27, 28 and 29 corresponding to valves 7, 8 and 9, and thence through branch pipe 26*a* to reservoir 9*a* and branch pipe 26*b* to turbine 21 through heating means. The heating means is shown as a combustion chamber 30 burning solid, liquid or gaseous fuel supplied to burner 31 by fuel pipe 32. In this complete system the total number of compressors need not equal the total number of turbines, provided that compressor capacity be sufficient to store, by running during the greater part of the day (while load on the network 3 is low), the quantity of air necessary to run the total gas turbine plant during the working hours of the day. The number of compressors running can be regulated in accordance with the load on the system and at certain times of day there may be some but not all of the turbines running on load while some but not all of the compressors are operating. Switches 34 and 24 may be closed at the same time, so that network 3 supplies the current for motor 33, but the switch 24 may be open while switch 34 is closed and valve 41 is closed: the energy for supplying motor 33 will come from some other source connected to the network. Thus the gas turbine plant of Fig. 2 can operate in parallel with coal-consuming steam-power driven generator plant (not shown) connected to the network 3 which, during the slack period, can supply current to the motor 33 for driving the compressor unit 25 to store air. A coal burning indirect heating system could be substituted for the combustion chamber 30.

In the arrangements of Fig. 2, since the compressors 5 and 25 are not mechanically coupled to the turbines 1 and 2 there is the advantage that the turbine does not have to be speed-matched with the compressor.

For varying the compressor speed, the electric motor may be a Schrage motor as indicated at 18, its speed being varied by relative movement of brushes 18*a* and 18*b* over commutator 18*c*. Alternatively it may be a motor such as 33 supplied through variable frequency-changer 35.

The reservoirs shown at 9 and 9*a* would probably be parts of one common reservoir system, depending however upon the relative location of turbines 1 and 21. Preferably each reservoir is a loaded accumulator storing air at approximately constant pressure. Thus the air may be stored underground in natural or at least partly artificially-formed reservoirs 9, 9*a* . . ., and with such underground storage, water displacement from a surface or underground reservoir 20, 20*a* . . . . at constant head may be used to maintain approximately constant storage pressure. Since the initiation and interruption of the flow of air from each compressor to the reservoir depends upon a small change of air pressure only sufficient to operate the non-return valve 7 or 27 some control may be effected by use of a booster pump 23 or 23*a* to vary the reservoir pressure by varying the head of water.

By pumping air at a reduced rate into the reservoir when the external load is light it is possible to store a surplus of air available on occasion to assist in carrying overloads which are beyond the capacity of the heat source 11. For this purpose one of the valves 38, 38*a* can be opened to supply the air turbine 37 driving the generator 39 which can be connected to the network 3 through which 40.

The exhaust pipe 6*c* from turbine 1 may pass through waste-heat-recovery system 36, and since the turbine 1 may run all day it is possible to supply a system 36 which requires heat mainly or only when the main load is not on the generator 2.

In an emergency, if the stored air is temporarily exhausted, a part load can be carried by closing valve 8 or 28 and running turbine 1 or 21 on air delivered by its own compressor 5 or 25, in conventional manner.

The invention may be applied to plant for only intermittent use, the plant then operating automatically to keep up the store of air. After such a plant has been running to drive a load for a short while, by drawing air from the reservoir, means which respond to the removal of the load from the turbine and which also respond to the reduction of sto... in the reservoir combine to cause engagem...

of the coupling or electrical transmission between the turbine and compressor; the turbine then drives the compressor to re-charge the reservoir until means responsive to the restored full charge of the reservoir shut-down the turbine, whereupon a valve is closed to prevent any discharge from the reservoir to either the compressor or the heating means.

What we claim is:—

1. A power system including a compressed air storage reservoir for supplying air to a gas turbine, a source of heat for heating the air on its way from the reservoir to the turbine, a charging compressor for supplying air to the reservoir, energy supply connections from the turbine to means absorbing the useful power of the system and to the charging compressor for sharing the turbine energy between these two, and means for varying turbine energy supplied by the energy supply connection to the charging compressor so that the latter can absorb turbine energy on occasion.

2. A power system according to claim 1 characterised by an engageable and disengageable driving connection between said compressor and the said turbine.

3. A power system according to claim 1 including an electric power network and an electric generator driven by said turbine and supplying said network, characterised by an electric motor driving said compressor unit and switchgear for connecting said motor to and disconnecting it from said generator.

4. A power system according to claim 2 or 3 wherein the external load on said gas turbine has a daily duration of about one third of a day, characterised in that the said turbine has a power capacity about equal to and at least as large as the full external load on it, the compressor has about the same power capacity, and the said source of heat is an atomic pile having a heat output capacity sufficient for operating the turbine at about one third of the full external load, so that turbine and source of heat can operate for about one third of the day for supplying external load and the remainder of the day for storing air.

5. A power system according to claim 1 including an electric power network which can receive electrical supply from sources which include a generator driven by said turbine, characterised in that said compressor unit is driven by an electric motor connected to said generator.

6. A power system according to claim 1 characterised by means for varying the speed of the compressor unit.

7. A power system according to claim 1 or Claim 6 characterised in that said compressor unit has angularly adjustable blades.

8. A power system according to claim 3 or claim 5 characterised in that the speed of said electric motor can be varied.

9. A power system according to any of the claims 1 to 8 characterised by a valve arrangement which includes a vent valve at the compressor outlet and a non-return valve between the reservoir and the compressor unit, and which allows the reservoir to be isolated or to be disconnected from the compressor unit while remaining connected to the turbine.

10. A power system according to any preceding claim characterised in that said reservoir is a loaded accumulator.

11. A power system according to claim 9 characterised in that said reservoir is an accumulator loaded to store air at a predetermined pressure and including means for varying said pressure.

12. A power system according to any preceding claim characterised in that the output of the said turbine is controlled by variable partial admission thereto.

13. A power system according to any preceding claim characterised by an auxiliary air turbine which can be connected, on occasion, to the said reservoir and be driven by air therefrom to supply supplementary energy to the rest of the power system.

14. A process for generating power including the steps of establishing a storage zone of compressed air, withdrawing air continuously from said zone, heating the air withdrawn and expanding the air thereby heated in a prime mover to produce a substantially constant power output, applying at least part of the power output to meet a varying load demand, and when the load demand is less than the constant power output utilising the surplus power to compress air into said zone.

15. A power system substantially as illustrated in and described herein with reference to Fig. 1 or Fig. 2 of the accompanying drawings.

E. CLEMENCE,
Chartered Patent Agent,
Agent for the Applicants.

PROVISIONAL SPECIFICATION

No. 26934 A.D. 1953

Power System Incorporating a Gas Turbine

We, POWER JETS (RESEARCH AND DEVELOPMENT) LIMITED, a British Company of 25, Green Street, London, W.1. do hereby declare this invention to be described in the following statement:—

In the common form of continuous combustion type gas turbine an air compressor driven by the turbine itself supplies air wh[illegible]

is heated by a heating arrangement—e.g. a combustion system burning fuel in the air—to provide motive fluid for the turbine. Usually, for each 1 h.p. of useful output the compressor requires about 2 h.p. to drive it and the turbine has to have a power capacity of 3 h.p. This makes a total capacity of 5 h.p. for the two machines. The heating arrangement must have a capacity corresponding to the useful output.

To reduce the bulk and cost of the rotary machines it has been proposed to supply a gas turbine with combustion products produced by burning fuel in air drawn from an air-storage reservoir, located underground, and supplied with air by any form of compressing means independent of the turbine, which accordingly does not drive a compressor.

A prime mover is seldom loaded fully for more than a small part of the day and may be entirely unloaded for a part of the day: industrial loads, for example, usually continue for about only eight hours a day. Thus if the combustion system of the common form of plant outlined above be replaced by some form of heat exchanger for heating the air by transference of heat from an atomic pile or other source of heat of high capital cost, this source is utilised uneconomically by being used for only eight hours a day, instead of being employed as a continuous and steady source of heat.

The present invention is concerned with an arrangement for enabling a part-time load to be supplied, the bulk and cost of the rotary plant and the heater being reduced by keeping the turbine running continuously or for longer periods than the load lasts. One aspect of the invention makes use of the fact that the power necessary to supply the air for the turbine is about twice the useful power output, to allow the turbine to be used to drive the load for one-third of the day and to pump air for storage for the remaining two-thirds of the day.

Power plant according to the invention is made up of a turbine unit of h.p capacity substantially equal to the full load h.p. of the external load, a compressor unit of about the same capacity in driving connection with the turbine, and adapted to supply air to the turbine, and air-storage reservoir adapted either to receive air from the compressor unit or to supply air to the turbine unit, means for reducing the rate of supply of air from the compressor unit to the reservoir, and possibly interrupting the driving connection between the compressing unit and the turbine at will, and means for heating the air on its way to the turbine.

In one form of the invention the supply of air to the reservoir is reduced to zero by shutting down the compressor. For this purpose, the compressor may be disconnected by an interruption of the driving connection to the turbine. If such a turbine, relieved of external load and coupled to the compressor, be run for example for 16 hours, about one-third of the output of the compressor will be available to pump into the reservoir a sufficient quantity of air for eight hours running of the turbine; thus for the next eight hours of the day the turbine, disconnected from the compressor, can be used solely to drive the external load, the air being supplied from the reservoir at about twice the rate at which it was stored. The capacity of the heating arrangement will correspond to the power output for storing the air—i.e. to about one-third of full load; when load is being driven, the remaining two-thirds of the power is derived from the energy in the stored air. The air-heating means may be a heat exchanger in combination with an atomic pile, from which heat is transferred to the air; thus the heat exchanger may pass the air and a stream of fluid—in particular of molten metal—directly heated by the pile. Such an arrangement is inherently of expensive construction and the reduction in its capacity may be economically much more valuable even than the reduction in the bulk and cost of the rotary plant. Moreover, the invention makes possible to use of the waste heat from some plant which operates all day.

The driving means between turbine and compressor may be mechanical—e.g. a frictional or positive clutch with an electromagnetically operated means for engaging it at will. It may alternatively be an electric transmission. The invention is particularly applicable to a gas turbine driving an electric generator, the load then being removed from the turbine by switching off external load in the output circuit of the generator. In such a case the compressor may be driven by an electric motor supplied by the generator and switched on when the load is switched off.

Some form of valve device—which may be automatic and pressure-responsive—may disconnect the shut-down compressor from the reservoir while leaving the latter connected to the heating means.

In a modification the compressor unit includes a variable-output compressor which can be brought into operation to supply a certain amount of air to the reservoir when the external load is reduced below full load. Thus the compressor may remain always driven by the turbine but may be of the partial admission type controlled by a valve arrangement so that its output can be adjusted to various different values over a range from zero (when full load is being supplied) to full output when there is no external load. The compressor may be variable by blade swivelling or may be driven at variable speed through a variable gearbox. In any case there may be one compressor for supplying the heater and turbine and another for supplying the [illegible] the reservoir. Preferably [illegible]

invention the reservoir is a loaded accumulator storing air at constant pressure.

The invention may be applied to fuel-burning turbine plant for only intermittent use, the plant then operating automatically to keep up the store of air. After such a plant has been running to drive a load for a short while, by drawing air from the reservoir, means which respond to the removal of the load from the turbine and which also respond to the reduction of store in the reservoir combine to cause engagement of the coupling or electrical transmission between the turbine and compressor; the turbine then drives the compressor to recharge the reservoir until means responsive to the restored full charge of the reservoir shut-down the turbine, whereupon a valve is closed to prevent any discharge from the reservoir to either the compressor or the heating means.

E. CLEMENCE,
Chartered Patent Agent,
Agent for the Applicants.

PROVISIONAL SPECIFICATION

No. 20502 A.D. 1954

Power System Incorporating a Gas Turbine

We, POWER JETS (RESEARCH AND DEVELOPMENT) LIMITED, a British Company, of 25 Green Street, London, W.1, do hereby declare this invention to be described in the following statement:—

In our co-pending Patent Application No. 26934/53 we have set forth a form of gas turbine power plant of the kind which, for supplying only a part-time external load, utilises air storage to reduce the bulk and capital cost of the plant.

One specific construction set forth includes a turbine unit of h.p. capacity substantially equal to the full load h.p. of the external load, a compressor unit of about the same capacity, an air storage reservoir, air-heating means, and a disengageable coupling between the turbine and the compressor unit. For about 16 hours a day the turbine, relieved of external load and coupled to the compressor, can pump into the reservoir about one-third of the compressor output, to store a sufficient quantity of air for eight hours running of the turbine. The coupling can then be disengaged and the turbine, disconnected from the compressor, can be used for about 8 hours solely to drive the external load, by using air supplied from the reservoir through heating means at about twice the rate at which it was stored. In a modified construction, also set forth, as applied to a turbine for driving an electric generator, the disengageable coupling is omitted and the compressor is permanently coupled to an electric motor: for about 16 hours a day the electric motor, driving the compressor to store air, is supplied by the generator driven by the turbine while for the subsequent eight hours the motor is switched off and the generator is used to supply the external load. This modification has the advantage of not requiring a disengageable coupling and operating means therefor.

The present invention consists in a further modification. An important use of the invention is in a gas-turbine-driven electric generating plant operating, in parallel with other generators driven either by gas turbines or by other prime movers and possibly in several interconnected power stations, to supply current to an electric supply network. According to the present modification the compressor can then be driven by an electric motor supplied from the network while the gas turbine is at rest. Furthermore, the number of compressors need not necessarily correspond to the number of turbines provided that the total compressor capacity be sufficient to store, by rubbing during the greater part of the day (while load on the supply system is low), the quantity of air necessary to run the total gas turbine plant during the working hours of the day. The number of compressors running can be regulated in accordance with the load on the system and at certain times of day there may be some but not all of the turbines running on load while some but not all of the compressors are operating. The gas turbine plant can operate in parallel with steam plant which, during the slack period, supplies current for driving the compressor to store air.

The heating means can be an atomic pile or other indirect heater, or a combustion system using solid liquid or gaseous fuel. The modified system can improve the economy of an oil-burning gas turbine since about two-thirds of its output could be derived from energy in air stored from a compressor driven by a motor supplied by a steam-power-driven generator—i.e. energy derived indirectly from coal burnt in the steam power plant. A coal-burning indirect heating system could also be used economically.

A system in which the compressor is not mechanically coupled to the turbine has the further advantage that the turbine does not have to match with the compressor.

As with the forms according to the said co-pending Application, the air may be stored in steel vessels, or underground in natural or at least partly artificially-formed reservoirs, and with such underground storage

water displacement from a surface or underground reservoir may be used to maintain approximately constant storage pressure.

E. CLEMENCE,
Chartered Patent Agent,
Agent for the Applicants.

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